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MTR-1783

DETERMINATION OF RECEIVER DYNAMIC RANGE BY MEANS OF INPUT INTERCEPT POINTS

Paul Krenitsky

AUGUST 1970

Prepared for

AEROSPACE INSTRUMENTATION PROGRAM OFFICE
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

This document has been approved for public release and sale; its distribution is unlimited.

Project 705E

Prepared by

THE MITRE CORPORATION
Bedford, Massachusetts

Contract F19(628)-68-C-0365

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FOREWORD

This Technical Report was written by Mr. Paul Krenitsky of The MITRE Corporation, Bedford, Massachusetts, under contract number F19(628)-68-C-0365 Project 705E and sponsored by the Aerospace Instrumentation Program Office, Electronic Systems Division, Air Force Systems Command, L. G. Hanscom Field, Bedford, Massachusetts.

REVIEW AND APPROVAL

This technical report has been reviewed and is approved.

George T. Galt

GEORGE T. GALT, Colonel, USAF
Director, Aerospace Instrumentation
Program Office

ABSTRACT

An investigation was conducted to find a practical method of performing an input intercept point test for the CORTS program. This test was applied to several current models of telemetry receivers in the MITRE telemetry laboratory and the results are presented in this report. Additional types of receiver tests were conducted in order to work out standard test procedures for the Telemetry Working Group (TWG), Receiver/Transmitter Committee of IRIG.

ACKNOWLEDGMENTS

Acknowledgment is given to Neil Heenan of MITRE who initially established the IIP specification in the CORTS receiver document and who has been helpful in subsequent discussions. Fruitful discussions have been held with Harold Jeske of Sandia on the whole range of receiver tests. Al Aho of MITRE performed the laboratory tests.

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SECTION I

INTRODUCTION

It is the purpose of this report to document the results of several months of effort performed in the MITRE telemetry laboratory on receiver-testing procedures. The investigation was initiated in order to develop a procedure for performing the test for the input intercept point (IIP), a new parameter that was written in the CORTS (Conversion of Range Telemetry Systems) program specification. The IIP plot graphically portrays the minimum frequency separation possible in a system if the dynamic range of the receiving system is not to be decreased by the generation of IM products.[2]

Other tests were performed in support of MITRE's participation in the Telemetry Working Group (TWG), Receiver - Transmitter Committee of IRIG (Inter-Range Instrumentation Group). In 1968 an ad hoc sub-committee was formed to publish detailed descriptions of all possible performance tests on a telemetry receiver with a view to standardizing the methods of testing. The term "performance" at this time is being broadly defined to include some tests that may be used by a designer of receivers, some tests that would be conducted at a vendor's plant when performing an acceptance test, and all tests that would be conducted at a range by operating personnel to assure themselves that the receiver is functioning properly. It is expected that this document on standard tests for telemetry receivers will be ready for publication at the time of the October 1970 meeting. The work in the MITRE telemetry laboratory formed part of the background research for these standard tests.

SECTION II

INPUT INTERCEPT POINT (IIP)

1.0 GENERAL

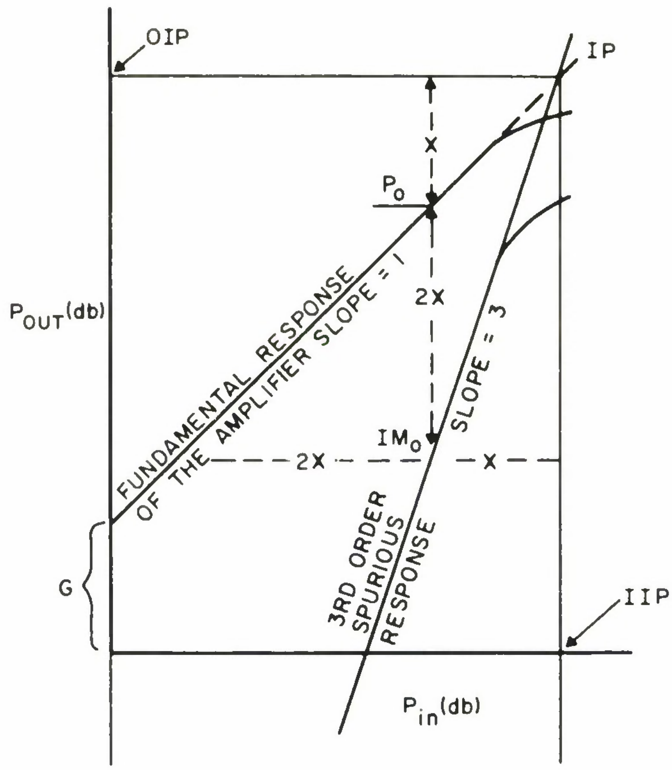
In this section, the input intercept point (IIP) will be discussed as follows:

- Definition of IIP;
- Guidelines for writing an IIP specification;
- Test setup for measuring the IIP; and
- Test results.

2.0 DEFINITION OF IIP

The input intercept point (IIP) is a specification that describes the overload characteristic of an amplifier or receiver. McVay[(1)] describes it as the intersection of the fundamental and third-order responses on a log-log scale when referred to the receiver input. Figure 1 is a graph showing the transfer characteristic of an amplifier with a slope of one and third-order intermodulation characteristic with its slope of three. The response of both curves becomes non-linear at high-power input levels but, if the linear sections of the characteristics are extrapolated, they intersect at a point, called the intercept point and labelled as IP in Figure 1. (There is a third point, the OIP, which is an IP referred to the receiver output.)

If two or more signals are introduced into an amplifier at the same time and if their level is increased, one can observe in the output the amplified versions of both the input and some intermodulation (IM) products. If two signals are used, the third-order IM products will be observable in the vicinity of the input signals for they are related to the input signals, f_1 and f_2, by the relationships of $2f_1 - f_2$ and $2f_2 - f_1$. If f_1 and f_2 are 1 MHz apart, the IM products of interest fall 1 MHz above the higher frequency and 1 MHz



OIP = OUTPUT INTERCEPT POINT
IIP = INPUT INTERCEPT POINT
IP = INTERCEPT POINT
P_o = POWER OUT
Pin = POWER IN
G = GAIN OF AMPLIFIER
IM_o = INTERMODULATION PRODUCTS MEASURED AT OUTPUT OF AMPLIFIER

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Figure I GRAPHICAL ANALYSIS OF IIP

below the lower frequency. Other products are formed that fall far outside this band of interest and are easily filtered out.

The output of an amplifier can be expressed as a power series with:

$$e_{out} = k_1 e_{in} + k_2 e_{in}^2 + k_3 e_{in}^3 + \ldots$$

if

$$e_{in} = e_1 \sin \omega_1 t + e_2 \sin \omega_2 t$$

In Appendix I, the expansion is shown to yield the following terms in the output:

$$e_{out} = \frac{1}{2} k_2 (e_1^2 + e_2^2) \tag{1}$$

$$+ \left[k_1 e_1 + \frac{3}{2} k_3 e_1 e_2^2 + \frac{3}{4} k_3 e_1^3 \right] \sin \omega_1 t \tag{2}$$

$$+ \left[k_1 e_2 + \frac{3}{2} k_3 e_1^2 e_2 + \frac{3}{4} k_3 e_2^2 \right] \sin \omega_2 t \tag{3}$$

$$- \frac{1}{2} k_2 e_1^2 \cos 2\omega_1 t \tag{4}$$

$$- \frac{1}{2} k_2 e_2^2 \cos 2\omega_2 t \tag{5}$$

$$- \frac{1}{4} k_3 e_1^3 \sin 3\omega_1 t \tag{6}$$

$$- \frac{1}{4} k_3 e_2^3 \sin 3\omega_2 t \tag{7}$$

$$+ k_2 e_1 e_2 \cos (\omega_1 - \omega_2) t \qquad (8)$$

$$- k_2 e_1 e_2 \cos (\omega_1 + \omega_2) t \qquad (9)$$

$$+ \frac{3}{4} k_3 e_1^2 e_2 \sin (2\omega_1 - \omega_2) t \qquad (10)$$

$$- \frac{3}{4} k_3 e_1^2 e_2 \sin (2\omega_1 + \omega_2) t \qquad (11)$$

$$+ \frac{3}{4} k_3 e_1 e_2^2 \sin (2\omega_2 - \omega_1) t \qquad (12)$$

$$- \frac{3}{4} k_3 e_1 e_2^2 \sin (2\omega_2 + \omega_1) t \qquad (13)$$

Terms (2) and (3) are directly proportional to the input signals if the non-linearities are ignored. The definition of intercept point ignores these non-linearities and uses only the linear portion of the characteristic; therefore, the fundamental response can be plotted with a slope of one. Terms (4), (5), (8), and (9), the second-order terms, are proportional to the square of the input signals and can be plotted with a slope of two. Terms (6), (7), (10), (11), (12), and (13) are proportional to the cube of the input and can be plotted with a slope of three.

Figure 1 does not show the plot of the second-order terms as they are far removed from the frequencies of interest. The terms which are likely to cause problems are (10) and (12) since they produce IM in the neighborhood of interest.

The intercept point (IP) is seen to be the intersection of the fundamental response of an amplifier and the third-order spurious response. In practice, this point can never be reached because of the non-linearities in both characteristics. Another way of defining IP is as follows: Two input signals, each x-db below the IP, will generate second-order products 2x-db below the IP and third-order products 3x-db below the IP. (This relationship is shown in Figure 1.) As shown in Figure 1, the output intercept point (OIP) can be expressed as:

$$OIP = \frac{3}{2}(P_o - IM_o) + IM_o$$

where

P_o = power out of amplifier

IM_o = level of third-order IM products at the output of the amplifier.

The output intercept point is also related to the input intercept point by:

$$OIP = IIP + G$$

$$IIP = \frac{3}{2}(P_o - IM_o) + IM_o - G$$

$$P_o = P_{in} + G$$

$$IIP = \frac{3}{2}P_{in} + \frac{1}{2}(G - IM_o)$$

This expression forms the guide for collecting test data.

3.0 GUIDELINE FOR WRITING AN IIP SPECIFICATION

The IIP plot, as stated earlier, graphically portrays the minimun frequency separation possible in a system if the dynamic range of the receiving system is not to be decreased by the generation of IM products.[2] Figure 1 showed the intercept point for one particular frequency -- generally the center of the passband. A useful plot for an amplifier or receiver is one, however, that shows the variation of IIP with frequency, removed from center frequency (f_o) as in Figure 2. This figure shows the separate plots of the various sections of a receiving system referred to the input of the preamplifier.

Dynamic range in a multi-signal environment will be defined as the range that exists between two or more signals of equal amplitude and the IM products that result from these signals. The measurement is usually made when IM products are first discernible above the noise threshold of the amplifier under test. The definition is based on the fact that, if the IM products get above the noise, the possibility then exists of these products masking a desired signal within the passband.

An example from reference 2 will show how the IIP can be used to determine the minimum frequency separation that the system will permit between adjacent carriers if the dynamic range of the channel is not to be reduced. Let the dynamic range for a receiver be specified as 60 db and extending from -40 dbm to -100 dbm. In Figure 1, this range is represented by the quantity 2x.

$$2x = P_o - IM_o = P_{in} - IM_{in} = \text{dynamic range}$$

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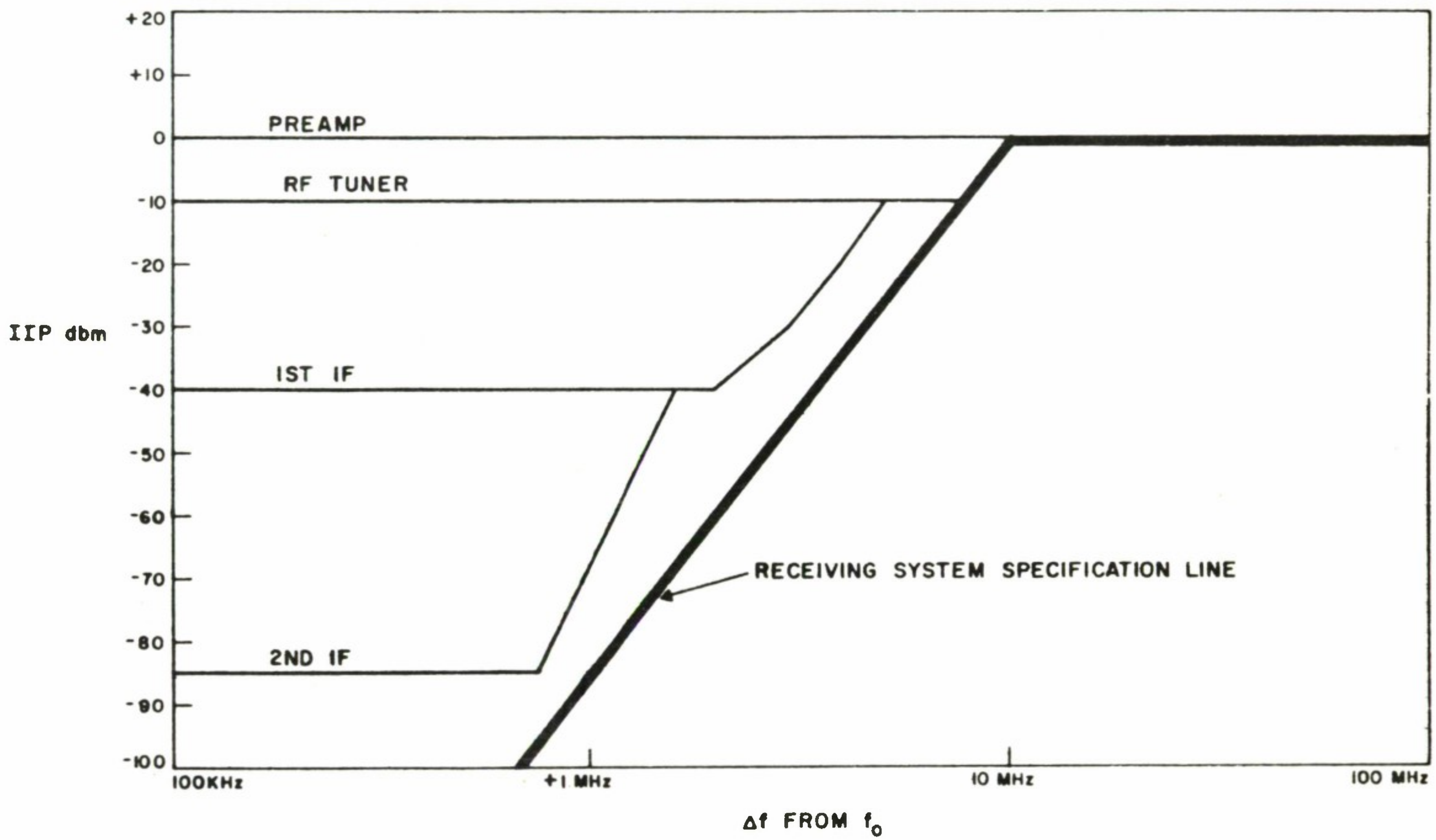


Figure 2 IIP VS Δf

IM_{in} is a conceptual way of relating the intermodulation in the output to the input terminal by the gain of the amplifier. As explained above, in order to avoid the masking of a desired signal, let IM_{in} be set equal to the minimum detectable signal into the receiver.

From Figure 1:

$$OIP = \frac{3}{2}(P_o - IM_o) + IM_o$$

Since the OIP = IIP + G:

$$IIP = \frac{3}{2}(P_{in} - IM_{in}) + IM_{in}$$

$$IIP = \frac{3}{2}(\text{Dynamic range}) + \text{min. det. signal}$$

$$IIP = \frac{3}{2}(60) - 100 = 90 - 100 = -10 \text{ dbm}$$

Figure 2 shows that an IIP = -10 dbm gives 8 MHz as the minimum frequency separation. As another example, if the minimum frequency separation is 5 MHz and the dynamic range is specified as 70 db (-20 to -90 dbm), the IIP will be:

$$IIP = \frac{3}{2}(70) - 90 = +15 \text{ dbm at 5 MHz}$$

If this number is too high for the preamplifier or amplifier design, either the dynamic range has to be reduced or the minimum frequency separation has to be increased.

A guideline for writing the IIP specification can be determined on the basis of minimum frequency separation between channels in a receiving system.

4.0 TEST SETUP FOR MEASURING IIP

4.1 Introduction

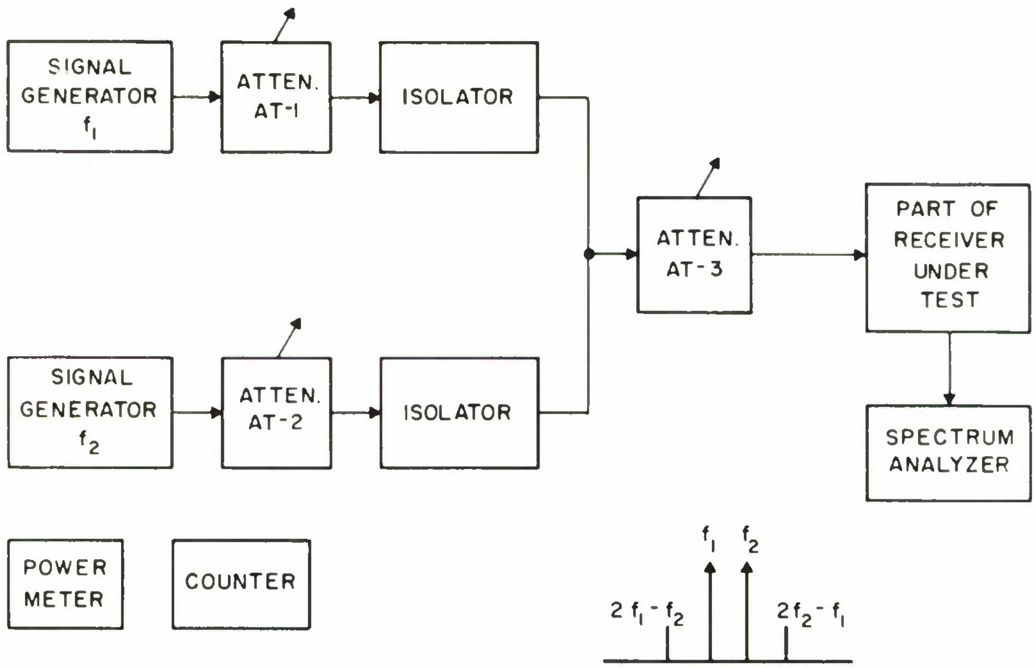
Figure 3 shows a test setup using two tones to create third-order IM in the amplifier under test. Laboratory tests have indicated that a receiver test should be conducted in three parts, as shown in Figure 4:

1. The RF preselector and fixed mixer;
2. The first IF amplifier and second mixer; and
3. The second IF amplifier, filter, and limiter.

This division follows the major changes in bandwidth in a receiver and it becomes fairly easy to collect data at these interfaces. The expression used for calculating the IIP is:

$$IIP = \frac{3}{2} P_{in} + \frac{1}{2} (G - IM_o)$$

A data sheet (similar to Tables I-IV) is made so that these quantities can be read and recorded. The test is run by placing both signals in the center of the passband, adjusting both amplifiers to be equal, and increasing the level of both until the IM products appear on the screen of the spectrum analyzer, as shown in Figure 3. The two input signals are separated by a small increment (about 100 KHz) on the spectrum analyzer and this separation is maintained in an approximate fashion as the frequencies are moved from the center of the band to the outer edges of the band.



EQUIPMENT REQUIRED (OR EQUIVALENT)

QTY	
2	SIGNAL GENERATORS (L & S BANDS), H-P 8614A
2	SIGNAL GENERATORS (1ST & 2ND IF), H-P 608E
1	COUNTER
1	POWER METER, GENERAL MICROWAVE 454A/422A
1	SPECTRUM ANALYZER, H-P 8552A/8553L
3	ATTENUATORS, KAY ELECTRIC 461A
2	L-BAND ISOLATORS
2	S-BAND ISOLATORS

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Figure 3 TWO-TONE TEST FOR MEASURING IIP

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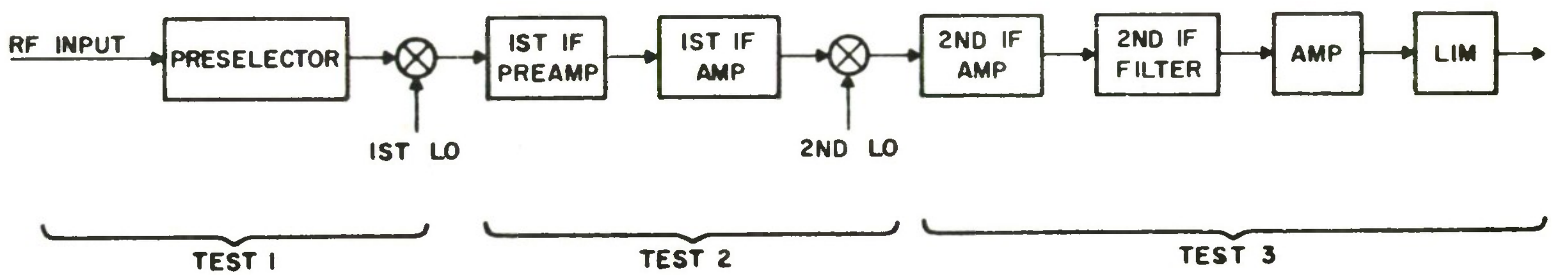

Figure 4 TYPICAL WAY OF SPLITTING RECEIVER INTO THREE PARTS FOR IIP TESTING

The only caution to be observed is to be sure that the unit is being tested on the linear part of its characteristic. From Figure 1 it can be seen that, if tested on the non-linear part of the curve, the IP will vary from test to test.

When the two input signals and two IM products are displayed on the spectrum analyzer, a test for IM occurring in the unit under test and not in the circuitry preceding it is run as follows:

In Figure 3, if f_1 and f_2 are adjusted for equal levels, changing f_1 by 1 db will change the amplitude of $2f_1 - f_2$ by 2 db and of $2f_2 - f_1$ by 1 db. Similarly, a change in f_2 by 1 db will change $2f_2 - f_1$ by 2 db and $2f_1 - f_2$ by 1 db. Changing the common attenuator, AT-3, by 1 db causes a 3-db change in both of the IM products.

The first test is run on the tuner with the spectrum analyzer connected to some convenient jack at the output of the mixer. The signal generator outputs are set in the middle of the band and moved out of band in 1-MHz increments with the spacing between f_1 and f_2 maintained to about 100 KHz. As the signals are moved about 10 to 15 MHz from the band center, the input power required to generate IM will become larger and larger until there is no more power available in the signal generators. This part of the test is concluded and the other side of the passband is then similarly tested. When both the L- and S-band tuners have been checked, the microwave-signal generators should be replaced with lower-frequency generators and the test repeated on the first IF amplifier and then the second IF amplifier.

When the data has been collected and the IIP values calculated, a graph of IIP versus Δf can be plotted on semilog paper. The paper originally used in Figure 2 (K & E 46 5813) has been found to be convenient since three cycles cover the frequencies of interest. If performance of the receiver alone is being plotted on the graph, the reference point will be at the RF input terminal and the IIP data on the RF tuner will be plotted first. Then the IIP data on the first

IF is tabulated and the gain of the tuner at the same frequencies is subtracted from these values.

This procedure is used to reference all IIP's of a chain of amplifiers to the same point. For the IIP of the second IF amplifier, the gain of the tuner and the first IF amplifier are summed together (at the matching frequencies) and then subtracted from the second IF IIP values (at the matching frequencies). The overall envelope of the receiver can then be plotted by following the second IF charactertistic until it intersects the first IF characteristic and following this until it intersects the tuner characteristics. The plot will look similar to Figure 2, on which also is plotted the preamplifier IIP and the specified limit line for the receiving-system.

4.2 <u>CORTS Receiver</u>

Data on the CORTS receiver (a Scientific Atlanta model 410M), tabulated in Tables I through IV, demonstrate how a typical graph, Figure 5, is drawn. (Only frequencies from band center to the upper edge of the passband are shown. (The region from band center down to the lower edge of the passband is approximately symmetrical and is not shown here.) Table I contains data taken on the S-band tuner. The preselector has a bandwidth of 15 MHz and the tuner was set at a frequency of 2250 MHz. Readings were taken 1 MHz apart until there was no more power available in the signal generators. In Figure 5, these points are plotted and the effects of the four poles in the preselector can be seen as the curve bends upward at a slope approximately equal to 24 db per octave. Table II shows the data taken on the first IF amplifier and the second converter. This data is plotted in Figure 5 in two ways: as it appears in Table II and as referred to the input of the receiver. Table III shows the data on the second IF amplifier and filter, plotted in the same way as the data of Table II. Table IV is a convenient way of tabulating gains and IIPs in order to determine the referred values of the IIPs with respect to the receiver

Freq. f_1	Freq. f_2	P_{in} dbm	$\frac{3}{2} P_{in}$ dbm	P_o dbm	Gain db	IM_o dbm	$\frac{1}{2}(G-IM_o)$ dbm	IIP dbm
2250	2250.1	-30	-45	-8	22	-55	38.5	-6.5
2251	2251.1	-29	-43.5	-8	21	-55	38.	-5.5
2252	2252.1	-27.5	-41.	-8	19.5	-55	37.	-4.
2253	2253.1	-26.	-39.	-9	17	-55	36.	-3.
2254	2254.1	-24.5	-37.	-11	13.5	-55	34.	-2.5
2255	2255.1	-21.5	-32.	-13	8.5	-55	32.	-0.5
2256	2256.1	-14.5	-22.	-16	-1.5	-55	27.	+5.
2257	2257.1	-7.5	-11.	-19	-11.5	-55	22.	+10.5
2258	2258.1	-3.0	-4.5	-28	-25.	-72	23.5	+19.
2259	2259.1	*						
2260	2260.1							

*No more power available in signal generators.

CORTS Receiver, Scientific Atlanta Model 410M

S-band tuner

f_o = 2250 MHz

$$IIP = \frac{3}{2} P_{in} + \frac{1}{2} (G - IM_o)$$

Table I. S-Band Tuner Data for CORTS Receiver

Freq. f_1	Freq. f_2	P_{in} dbm	$\frac{3}{2} P_{in}$ dbm	P_o dbm	Gain db	IM_o dbm	$\frac{1}{2}(G-IM_o)$ dbm	IIP dbm
105	105.1	-62	-93	-15	47	-60	53.5	-39.5
106	106.1	-61	-92.5	-15	46	-60	53	-39.5
107	107.1	-60	-90.	-15	45	-60	52.5	-37.5
108	108.1	-56	-84	-16	40	-60	50	-34.
109	109.1	-51	-76.5	-18	33	-60	46.5	-30
110	110.1	-47	-70.5	-21	26	-60	43	-27.5
111	111.1	-43	-64.5	-23	20	-60	40	-24.5
112	112.1	-40	-60	-26	14	-60	37	-23.
113	113.1	-38	-57	-30	8	-60	34	-23.
114	114.1	-35	-52.5	-31	4	-60	32	-20.5
115	115.1	-32	-48	-33	-1	-60	29.5	-18.5

CORTS Receiver, Scientific Atlanta Model 410M

First IF Amplifier (403M) and 2nd Converter (404M)

f_o = 105 MHz

$$IIP = \frac{3}{2} P_{in} + \frac{1}{2} (G - IM_o)$$

Table II. First IF Amplifier Data for CORTS Receiver

Freq. f_1	Freq. f_2	P_{in} dbm	$\frac{3}{2} P_{in}$ dbm	P_o dbm	Gain db	IM_o dbm	$\frac{1}{2}(G-IM_o)$ dbm	IIP dbm
10.0	10.0	-37	-55.5	-16	21	-60	40.5	-15
10.5	10.6	-36	-54.	-16	20	-60	40.	-14
11.0	11.1	-32	-48.	-17	15	-60	37.5	-10.5
11.5	11.6	-25	-37.5	-18	7	-60	33.5	-4.
12.0	12.1	-17	-25.5	-20	-3	-60	28.5	+3.
12.5	12.6	-13	-19.5	-25	-12	-60	24.	+4.5
13.0	13.1	-11	-16.5	-32	-21	-60	19.5	+3.0

CORTS Receiver, Scientific Atltanta Model 410M

Second IF Linear Phase Filter (431-LP-1.5 MHz)
and Second IF Amplifier (405A)

$f_o = 10$ MHz

$$IIP = \frac{3}{2} P_{in} + \frac{1}{2} (G - IM_o)$$

Table III. Second IF Amplifier Data for CORTS Receiver

Δf MHz	S-Band Tuner Gain db	1st IF IIP	1st IF IIP Referred	1st IF Gain	G Tuner and G 1st IF	2nd IF IIP	2nd IF IIP Referred
0	22	-39.5	-61.5	47	69	-15	-84
0.5	22	-39.5	-61.5	47	69	-14	-83
1.0	21	-39.5	-60.5	46	67	-10.5	-77.5
1.5	20	-38.5	-58.5	46	66	-4.	-70.
2.0	19.5	-37.5	-57	45	64.5	+3.	-61.5
2.5	18.	-36	-54	42	60	+4.5	-55.5
3.0	17	-34	-51	40	57	+3.0	-54
4.0	13.5	-30	-43.5	33	46.5		
5.0	8.5	-27.5	-37	26	34.5		
6.0	-1.5	-24.5	-23				
7.0	-11.5	-23	-11.5				
8.0	-25	-23	+2				

Table IV. Referred Values of IIP, CORTS Receiver

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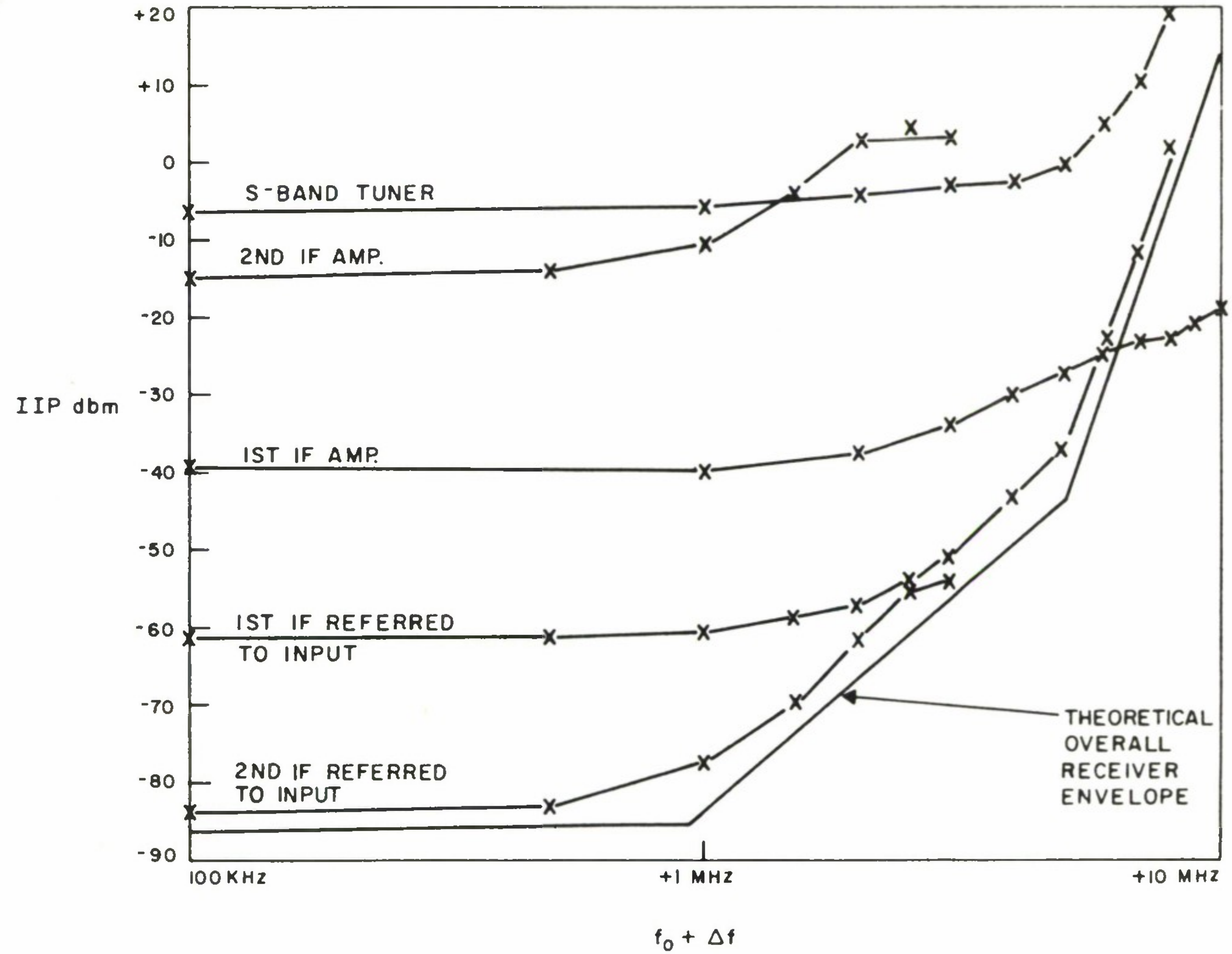

CORTS RECEIVER SCIENTIFIC ATLANTA 410M, S-BAND TUNER, UPPER PART OF BAND, f_o = 2250 MHz, LINEAR PHASE.

Figure 5 IIP VS FREQUENCY

input. Figure 5 shows all of these plots on one graph. For simplicity, one could ignore the plots of the first and second IFs and only consider those which are referred to the input. The overall receiver envelope line would be drawn to the right of the second IF referred, the first IF referred, and the tuner. (If an RF preamplifier were part of the receiving system, all parts of the receiver would be referenced to that.) All tests were run with the manual gain control set to a point near maximum gain.

4.3 DEI Receiver

Figure 6 is a plot of data taken on a Defense Electronics, Inc. model TR-711 (5) receiver with an S-band tuner. The receiver was equipped with a narrow second IF filter, which was bypassed in order to get more data points. The filter was a 500-kHz, 7-pole, constant-amplitude filter which attenuated the signal very rapidly so that little data could be obtained beyond 400 kHz. With the filter bypassed, the overall bandwidth was somewhere between 3 and 4 MHz. The overall receiver envelope is shown in Figure 6. This receiver was not equipped with a manual gain control and the AGC was disabled for all tests.

4.4 ACL Receiver

Figure 7 is a plot of an ACL model TR 104A receiver with the L-band tuner set at 1487 MHz. The second IF filter switch was set at the 2-MHz bandwidth position and the manual gain set near maximum.

4.5 Space General Receiver

Figure 8 is a plot of a Space General RTD-5000 receiver with a VHF tuner. The second IF filter was bypassed when data was taken.

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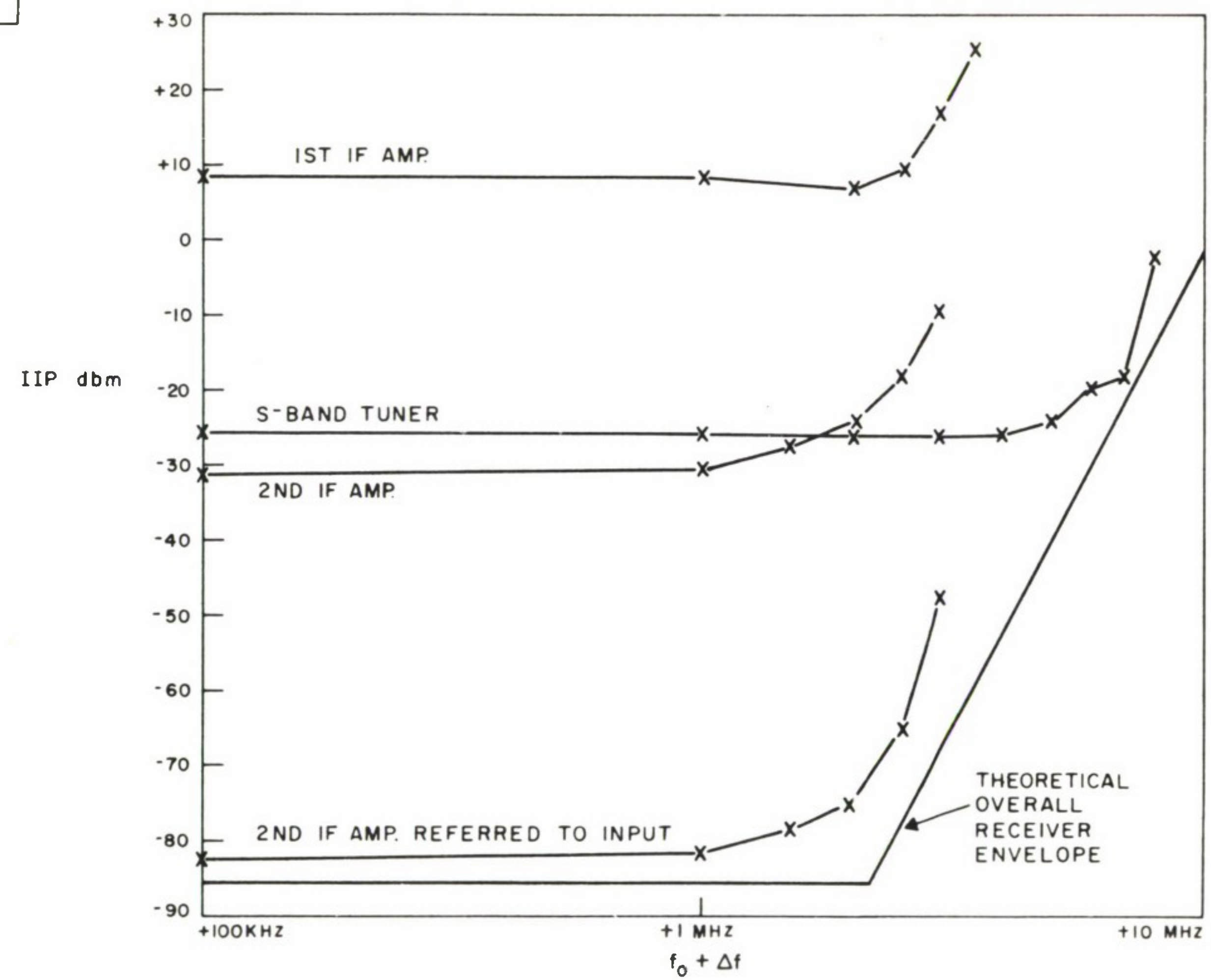

DEI TR-711(5), S-BAND TUNER, UPPER PART OF BAND, f_o = 2250 MC

Figure 6 IIP VS FREQUENCY

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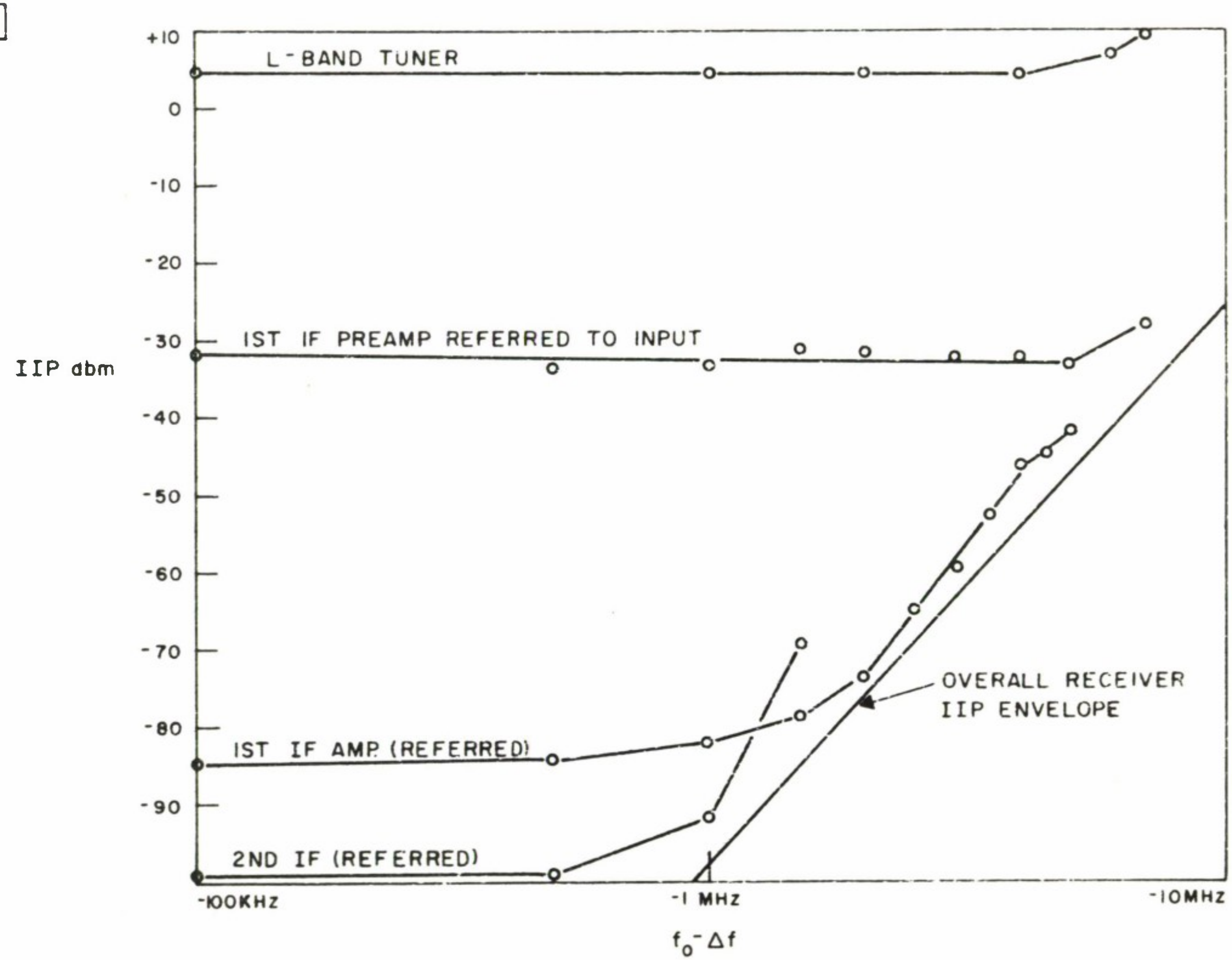

ACL TR 104A RECEIVER, L-BAND TUNER, f_o = 1487 MC, 2 MC IF FILTER, MAN. GAIN SET AT -0.2 V ON AGC BUSS.

Figure 7 IIP VS FREQUENCY

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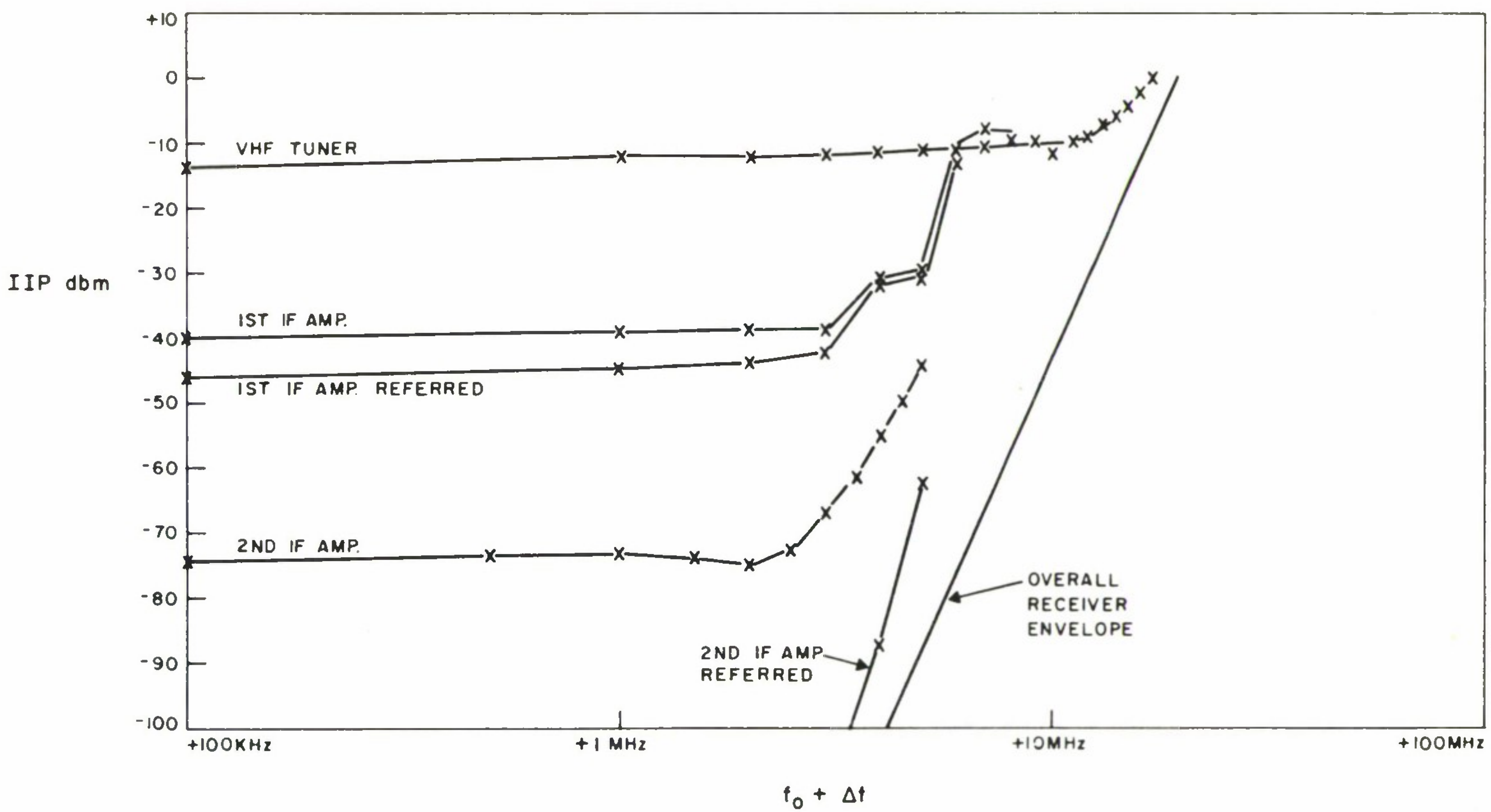

SPACE GENERAL RTD-5000 RECEIVER, VHF TUNER, f = 350 MHz, IF FILTER BYPASSED.

Figure 8 IIP VS FREQUENCY

SECTION III

ADDITIONAL TESTS FOR IRIG (TWG)

1.0 INTRODUCTION

A list of nineteen other types of tests were reviewed in order to assist the Telemetry Working Group (TWG) ad hoc committee. Five tests were selected for careful testing, some in order to help in the preparation of test procedures for review by this group. The five tests studied in detail are summarized in the remainder of this report.

2.0 NOTCH NOISE

The Notch Noise Test[3,4] was performed in the telemetry laboratory with the equipment shown in Figure 9. Normally, these kinds of tests are performed, as by Harold Jeske and others[5] at Sandia, with a Marconi White Noise Test Set, model OA 2090A, which consists of a transmitting package and a receiver package. Since limited funds permitted purchase of only a few filters, the equipment shown in Figure 9 was used to obtain the results shown in Figure 10. Notch depth indicates the extent of distortion and intermodulation that a frequency division multiplex signal will suffer as it passes through the filters of a receiver. The test is run using random noise as the modulating signal deviated approximately $\pm \frac{1}{4}$ of the IF bandwidth. If the deviations become too great, the notch depth becomes smaller because signal energy is falling outside of the 3-db bandwidths of the filter where phase non-linearities are more pronounced.

The TWG subcommittee will be considering the notch noise test as an indicator of receiver performance for frequency-multiplexed signals. There is a relationship between noise power ratio, phase linearity of the receiver's filters, and data quality of the FDM signal, and this relationship can be established by laboratory tests. The subcommittee expects that this work will be done during the next

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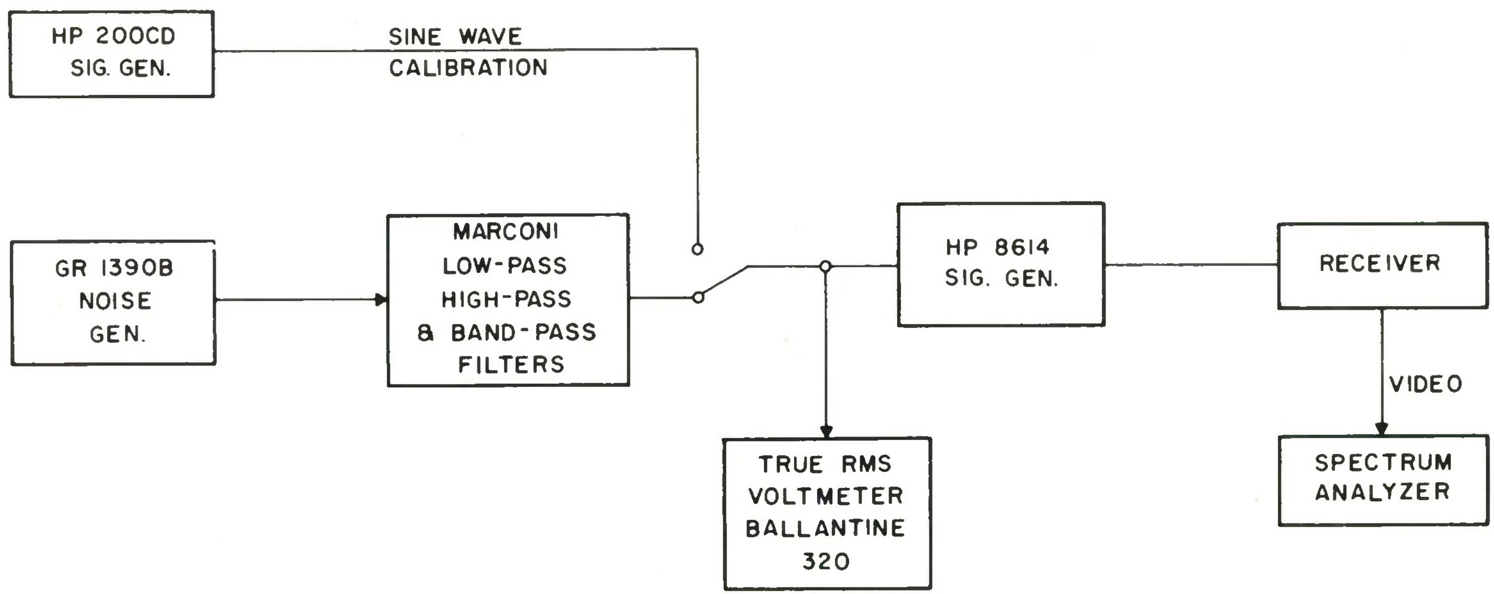
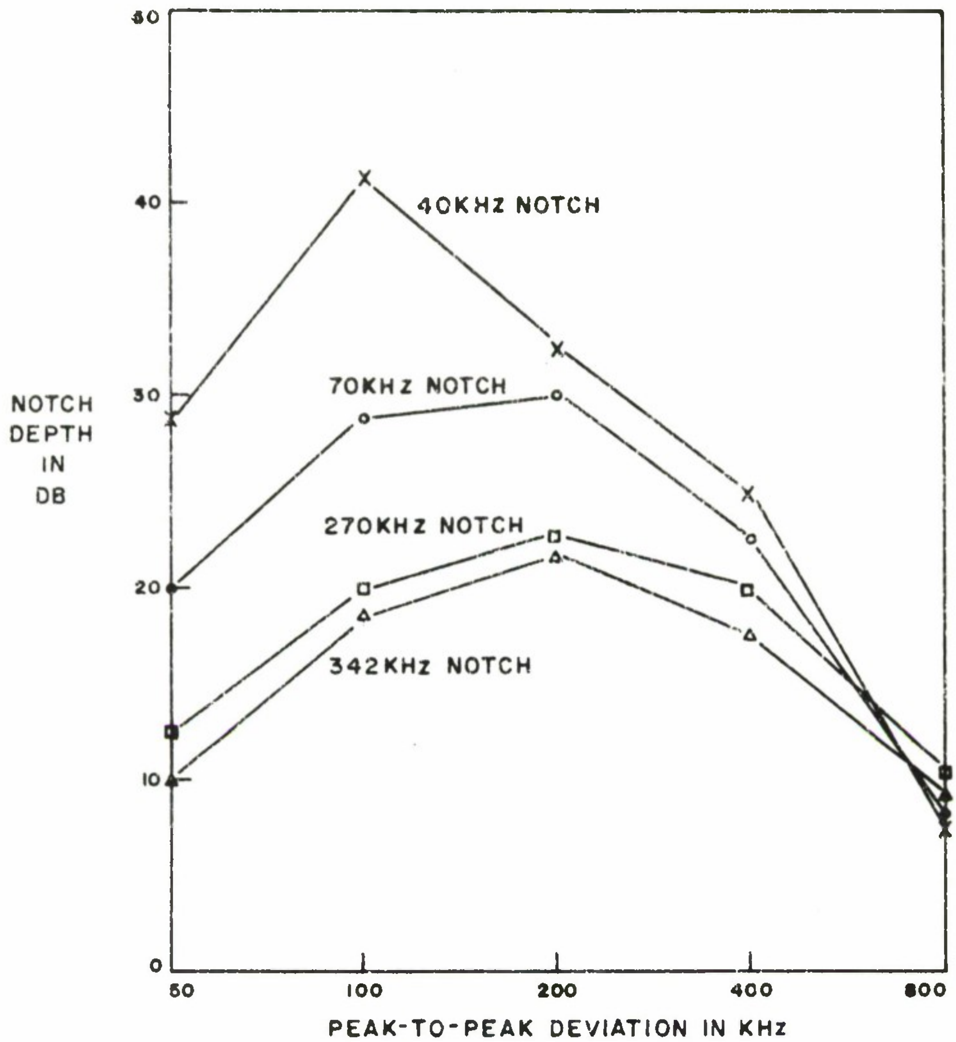


Figure 9 TEST SETUP FOR NOTCH NOISE TEST



NOTCH DEPTH VS DEVIATION, TYPICAL TELEMETRY RECEIVER WITH 1 MHz 2ND IF FILTER

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Figure 10 NOTCH NOISE TEST

year at the Naval Weapon Center Laboratory in Corona. That laboratory has been funded to do R&D work for TWG, and performance tests on receiving systems have priority.

3.0 INPUT VSWR

Receivers were checked for a VSWR less than 2:1. Figure 11a shows the equipment configuration for the test. A sweep generator, connected to a reflection coefficient bridge (Texscan KRCB-4), is adjusted to sweep the RF band being tested. One trace of the scope is connected to the output of the first mixer and this signal indicates to the observer the frequency setting of the receiver relative to the sweep generator output and, therefore, the point on the scope trace where the VSWR reading is to be made. The peaks and valleys will undulate as the receiver is tuned across the band and it would be difficult to determine exactly where to take the reading were it not for the mixer output trace. The VSWR trace is first calibrated by means of a known mismatch for a 2:1 deflection. When the receiver is connected to the bridge, the VSWR trace will be an irregular contour, as shown in Figure 11b.

The bridge is equipped with five calibrated mismatches, and several calibration lines can be marked on the scope face in order to determine the VSWR more accurately at any frequency.

4.0 LOCAL OSCILLATOR CONDUCTED INTERFERENCE

This test is a measure of how good the mixer balance is and how well the preselector is tuned. The specification may state, for instance, that the LO power appearing at the antenna terminal must be -80 dbm or lower. The test is easily performed by connecting a spectrum analyzer to the RF input and tuning it to the LO frequency. The analyzer is calibrated with a -80 dbm signal level and then both the analyzer and receiver are tuned across the band together.

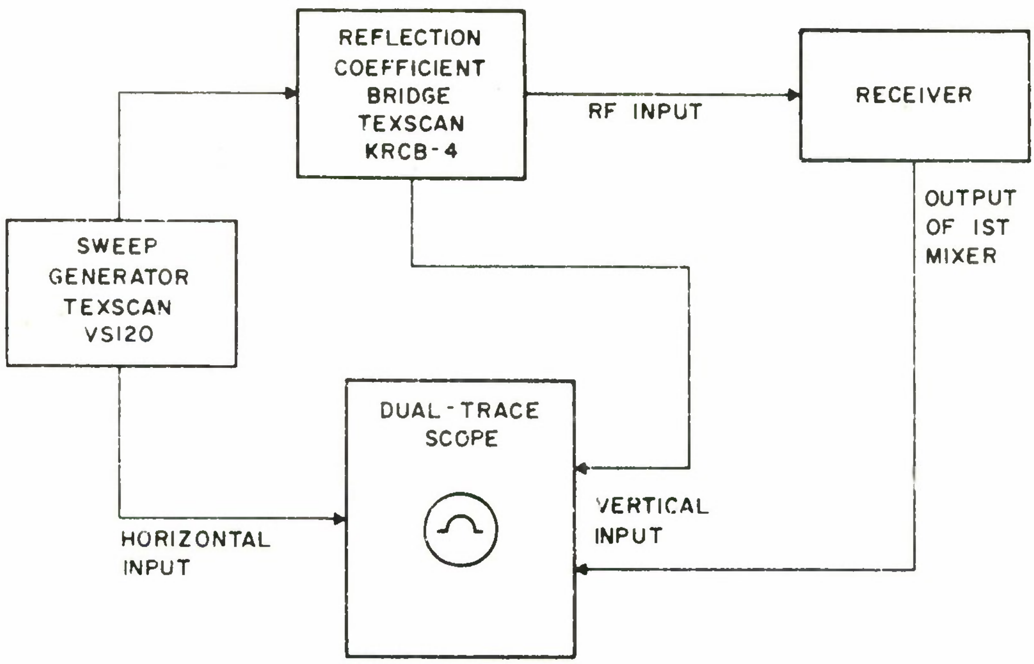

Figure 11 a INPUT VSWR TEST

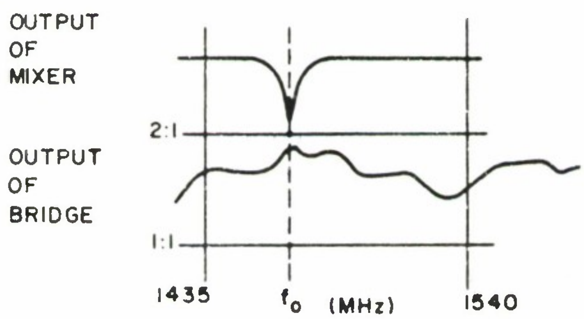

Figure 11 b SCOPE DISPLAY OF VSWR

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5.0 SPURIOUS RESPONSES

The test for spurious responses has been done according to the procedure outlined in MIL-STD-462, Method CS04, Conducted Susceptibility. This test measures the rejection of undesired signals at the input to the receiver and uses two signal generators -- one to produce a standard reference output and the other to produce a high-level source operating out-of-band. A typical specification might read that spurious responses due to all causes shall be at least 80 db below the desired signal. Figure 12 shows a receiver tested at both the L- and S-bands. The MIL specification calls for a frequency scan from 30 Hz to 10 GHz. The counter identifies the exact frequency of a spurious signal to help the receiver designer isolate and rectify the problem.

A test on self-generated spurious responses is conducted by terminating the RF input in 50 ohms and checking the second IF output with a narrowband spectrum analyzer. A typical specification requires that self-generated spurious responses be at least 27 db below noise, using a 500 kHz filter. The manual gain control is set at maximum in the receiver and the receiver is tuned across the band, using a 1 kHz bandwidth in the analyzer.

6.0 AGC RESPONSE TIME

A block diagram of this test is shown in Figure 13. A plot of the AGC voltage-versus-input signal is first made on a point-by-point basis. Then square-wave modulation is applied to amplitude-modulate the signal generator with RF steps of amplitude varying over a 50-db range. Some interesting results were observed on four different receivers whose AGC time constants were set at one millisecond. In Figure 14, receiver A shows that the AGC loop will overshoot and ring when it is subjected to signals that vary over this range of amplitudes. The published time constant of one millisecond actually requires 10 milliseconds to change from a weak to a strong signal condition.

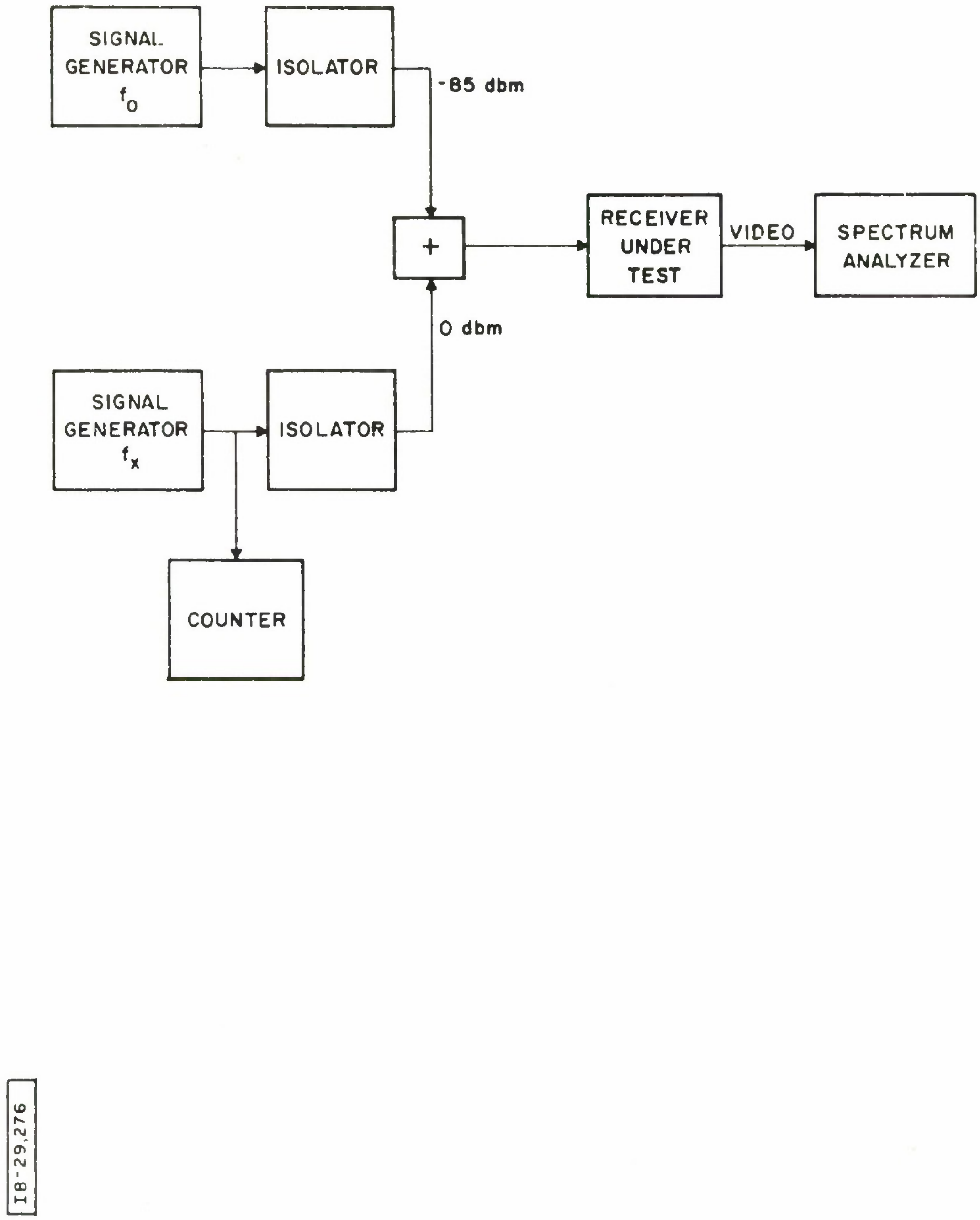

Figure 12 SPURIOUS RESPONSES

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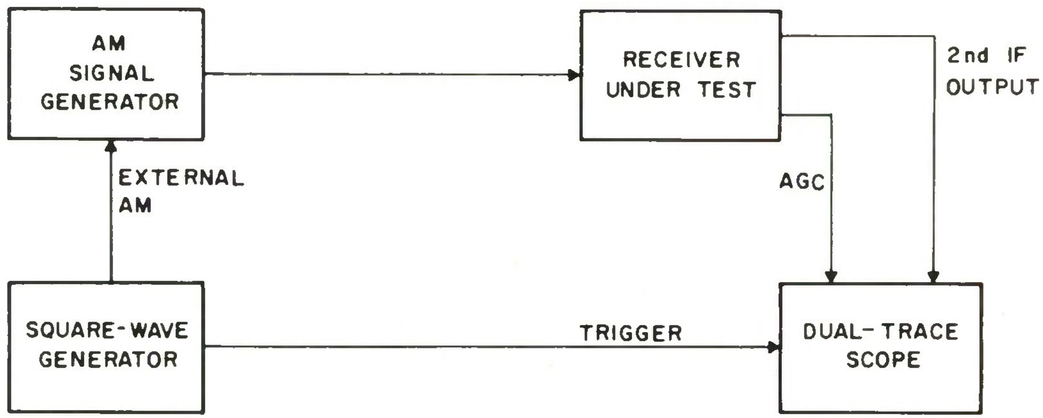
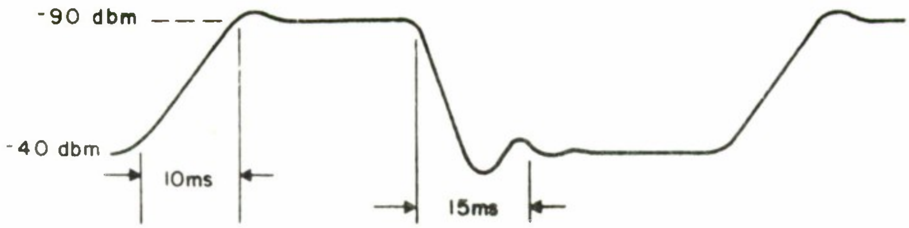
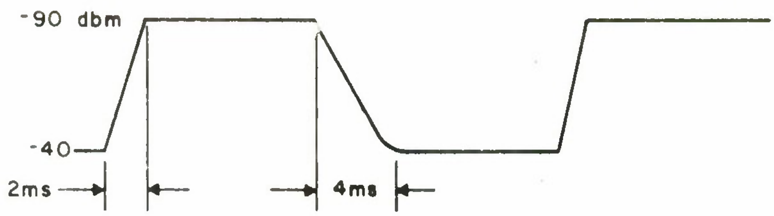


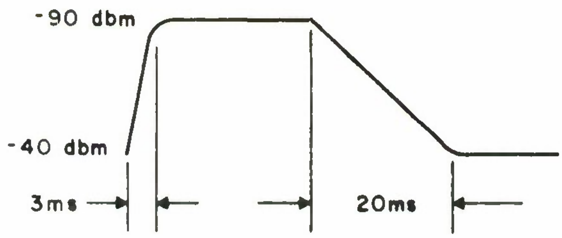
Figure 13 AGC RESPONSE TIME TEST



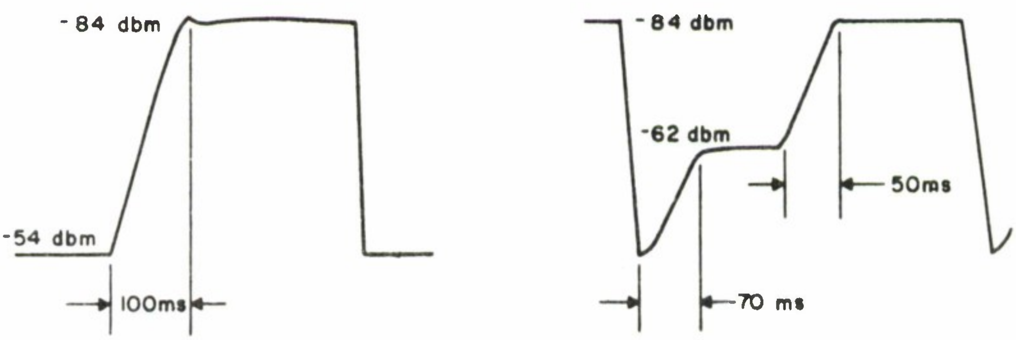
RECEIVER A TIME CONSTANT = 1 MILLISECOND



RECEIVER B TIME CONSTANT = 1 MILLISECOND



RECEIVER C TIME CONSTANT = 1 MILLISECOND



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RECEIVER D TIME CONSTANT ≈ 10 MILLISECONDS

Figure 14 RESULTS OF AGC RESPONSE TESTS

Receiver B has the response time that comes closest to matching the published figure. It can be seen that it has no overshoot or ringing and responds well to large changes in amplitude. Receiver C is similar to B in going from a strong to a weak signal condition but takes an inordinate amount of time to change from a weak to a strong signal condition. Receiver D points out the fact that the test should cover several ranges of amplitude. The first test involved a change of 30 db and the AGC response looks good but appears to be slow. The second test amounted to a change of 20 db and revealed a large overshoot in going from the weak- to the strong-signal condition.

The TWG subcommittee discussed this particular test at a January 1970 meeting and agreed that this type of test should be standardized so that vendors' claims could be measured with a standard test procedure.

APPENDIX I

If the output of an amplifier can be expressed as:

$$e_{out} = k_1 e_{in} + k_2 e_{in}^2 + k_3 e_{in}^3$$

and

$$e_{in} = e_1 \sin \omega_1 t + e_2 \sin \omega_2 t$$

then

$$e_{in}^2 = e_1^2 \sin^2 \omega_1 t + 2e_1 e_2 \sin \omega_1 t \sin \omega_2 t + e_2^2 \sin^2 \omega_2 t$$

and

$$e_{in}^3 = e_1^3 \sin^3 \omega_1 t + 3e_1^2 e_2 \sin^2 \omega_1 t \sin \omega_2 t$$

$$+ 3e_1 e_2^2 \sin \omega_1 t \sin^2 \omega_2 t + e_2^3 \sin^3 \omega_2 t$$

therefore

$$e_{out} = k_1 e_1 \sin \omega_1 t + k_1 e_2 \sin \omega_2 t + k_2 e_1^2 \sin^2 \omega_1 t$$

$$+ 2k_2 e_1 e_2 \sin \omega_1 t \sin \omega_2 t + k_2 e_2^2 \sin^2 \omega_2 t$$

$$+ k_3 e_1^3 \sin^3 \omega_1 t + 3k_3 e_1^2 e_2 \sin^2 \omega_1 t \sin \omega_2 t$$

$$+ 3k_3 e_1 e_2^2 \sin \omega_1 t \sin^2 \omega_2 t + k_3 e_2^3 \sin^3 \omega_2 t$$

Using the following trigonometric identities:

$$\sin^2 A = \frac{1}{2}(1 - \cos 2A)$$

$$\sin A \sin B = \frac{1}{2}[\cos(A - B) - \cos(A + B)]$$

$$\sin^3 A = \frac{3}{4}\sin A - \frac{1}{4}\sin 3A$$

$$\sin^2 A \sin B = \frac{\sin A}{2}[\cos(A - B) - \cos(A + B)]$$

$$\sin A \cos B = \frac{1}{2}[\sin(A + B) + \sin(A - B)]$$

$$\sin A \cos(A - B) = \frac{1}{2}[\sin(2A - B) + \sin B]$$

$$\sin A \cos(A + B) = \frac{1}{2}[\sin(2A + B) + \sin(-B)]$$

$$\sin^2 A \sin B = \frac{1}{4}[\sin(2A - B) + \sin B - \sin(2A + B) + \sin B]$$

Making use of these identities then yields:

$$\begin{aligned} e_{out} = {} & k_1 e_1 \sin \omega_1 t \\ & + k_2 e_2 \sin \omega_2 t \\ & + \frac{1}{2} k_2 e_1^2 (1 - \cos 2\omega_1 t) \\ & + k_2 e_1 e_2 [\cos(\omega_1 - \omega_2)t - \cos(\omega_1 + \omega_2)t] \\ & + \frac{1}{2} k_2 e_2^2 (1 - \cos 2\omega_2 t) \\ & + k_3 e_1^3 [\frac{3}{4} \sin \omega_1 t - \frac{1}{4} \sin 3\omega_1 t] \end{aligned}$$

$$+ \frac{3}{4} k_3 e_1^2 e_2 \, [\sin(2\omega_1 - \omega_2)t - \sin(2\omega_1 + \omega_2)t + 2 \sin \omega_2 t]$$

$$+ \frac{3}{4} k_3 e_1 e_2^2 \, [\sin(2\omega_2 - \omega_1)t - \sin(2\omega_2 + \omega_1)t + 2 \sin \omega_1 t]$$

$$+ k_3 e_2^3 \, [\frac{3}{4} \sin \omega_2 t - \frac{1}{4} \sin 3\omega_2 t]$$

Collecting terms

$$e_{out} = \frac{1}{2} k_2 \, (e_1^2 + e_2^2)$$

$$+ [k_1 e_1 + \frac{3}{2} k_3 e_1 e_2^2 + \frac{3}{4} k_3 e_1^3] \sin \omega_1 t$$

$$+ [k_1 e_2 + \frac{3}{2} k_3 e_1^2 e_2 + \frac{3}{4} k_3 e_2^3] \sin \omega_2 t$$

$$- \frac{1}{2} k_2 e_1^2 \cos 2\omega_1 t$$

$$- \frac{1}{2} k_2 e_2^2 \cos 2\omega_2 t$$

$$- \frac{1}{4} k_3 e_1^3 \sin 3\omega_1 t$$

$$- \frac{1}{4} k_3 e_2^3 \sin 3\omega_2 t$$

$$+ k_2 e_1 e_2 \cos (\omega_1 - \omega_2) t$$

$$- k_2 e_1 e_2 \cos (\omega_1 - \omega_2) t$$

$$+ \frac{3}{4} k_3 e_1^2 e_2 \sin (2\omega_1 - \omega_2) t$$

$$- \frac{3}{4} k_3 e_1 e_2^2 \sin (2\omega_1 + \omega_2) t$$

$$+ \frac{3}{4} k_3 e_1 e_2^2 \sin (2\omega_2 - \omega_1) t$$

$$- \frac{3}{4} k_3 e_1 e_2^2 \sin (2\omega_2 + \omega_1) t$$

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13. ABSTRACT

An investigation was conducted to find a practical method of performing an input intercept point test for the CORTS program. This test was applied to several current models of telemetry receivers in the MITRE telemetry laboratory and the results are presented in this report. Additional types of receiver tests were conducted in order to work out standard test procedures for the Telemetry Working Group (TWG), Receiver/Transmitter Committee of IRIG.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
UHF RECEIVERS						
TELEMETRY RECEIVERS						
RECEIVER OVERLOAD CHARACTERISTICS						
INTERMODULATION PRODUCTS						
SPURIOUS SIGNAL GENERATION						
DYNAMIC RANGE OF TELEMETRY RECEIVERS						
RADIO RECEIVER SYSTEMS						
L- AND S-BAND RECEIVERS						